

**Biodegradation of phenol and its derivatives in  
packed and moving bed bioreactors using *Bacillus* sp.  
isolated from petroleum site**



Thesis submitted in partial fulfillment for the

Award of degree

**DOCTOR OF PHILOSOPHY**

By

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# **Dedication**

*I dedicated this Ph.D. thesis to the 139 crore Indians who paid the cost of this study; I am greatly indebted to them*

## Undertaking from the Candidate

I, **Ganesh Swain**, a research scholar under the supervision of **Prof. B.N. Rai** and co-supervision of **Dr. Ravi P. Jaiswal**, Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi, India give undertaking that the thesis entitled "**Biodegradation of phenol and its derivatives in packed and moving bed bioreactors using *Bacillus* sp. isolated from petroleum site**" submitted by me for the degree of Doctor of Philosophy is a record of first-hand research work done by me during the period of study.

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## Declaration by the candidate

I, **Ganesh Swain**, certify that the work embodied in this Ph.D. thesis is my bonafide work carried out by me under the supervision of **Prof. B.N. Rai** and co-supervision of **Dr. Ravi P. Jaiswal** from **July 2017 to December 2021** at the Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi, India. The matter embodied in this Ph.D. thesis has not been submitted to award any other degree/diploma. I declare that I have faithfully acknowledged and given credit to the research workers whenever their works have been cited in the text and the body of the thesis. I further declared that I have not willfully lifted some other work, paragraph, text, data, results, etc., reported dissertations, thesis, etc., or available at websites and included them in this Ph.D. thesis and cited as my work.

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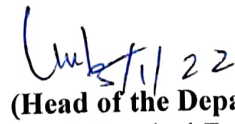
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# Table of contents

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| Content   | Page no.    |
|---|-------------|
| Certificate   | iii         |
| Declaration by the candidate & certificate by the supervisor              | iv          |
| Copyright transfer certificate  | v           |
| Acknowledgements  | viii        |
| Table of contents   | x           |
| List of Figures   | xvi         |
| List of Tables  | xix         |
| Abbreviations   | xxi         |
| Preface   | xxiii       |
| <b>Chapter 1: Introduction</b>  | <b>1-11</b> |
| 1.1 Introduction  | 1           |
| 1.1.1 Sources and pollution   | 1           |
| 1.1.2 Toxicity and permissible limit in the environment                   | 3           |
| 1.2 Treatment methods   | 4           |
| 1.2.1 Physical methods  | 4           |
| 1.2.2 Chemical and advanced oxidation methods                             | 5           |
| 1.2.3 Biological methods  | 6           |
| 1.3 <b>Factors affecting biodegradation of phenol and its derivatives</b> | <b>8</b>    |
| 1.3.1 Effect of pH  | 8           |

---

|   |   |              |
|---|---|--------------|
| 1.3.2   | Effect of temperature   | 8            |
| 1.3.3   | Effect of dissolved oxygen concentration                                      | 9            |
| 1.3.4   | Effect of phenolic concentration and other carbon sources                     | 10           |
| 1.3.5   | Effect of nutrients   | 10           |
| <b>Chapter 2: Literature review and Objective</b> |   | <b>12-27</b> |
| 2.1.  | Biodegradation of phenol and its derivatives by fungi, yeast,<br>and bacteria | 12           |
| 2.1.1   | Biodegradation by fungi and yeast   | 12           |
| 2.1.2   | Biodegradation by bacteria  | 13           |
| 2.2.  | Biodegradation of phenol and its derivatives                                  | 16           |
| 2.2.1   | Free cell system  | 16           |
| 2.2.2   | Immobilized system  | 17           |
| 2.3   | Bioreactors   | 17           |
| 2.3.1   | Sequencing batch reactor  | 18           |
| 2.3.2   | Airlift bioreactor  | 19           |
| 2.3.3   | Packed bed bioreactor   | 19           |
| 2.3.4   | Moving bed biofilm reactor  | 20           |
| 2.3.5   | Rotating biological contactor   | 21           |
| 2.3.6   | Trickling Biofilter   | 21           |
| 2.4   | Findings of the literature review and research gap                            | 24           |
| 2.5   | Objective of the work   | 27           |
| <b>Chapter 3: Materials and methods</b>           |   | <b>28-49</b> |

---

|   |  |    |
|---|--|----|
| 3.1                                     | Equipments, materials, and glassware   | 28 |
| 3.2                                     | Chemicals and reagents   | 28 |
| 3.3                                     | Experimental methods   | 29 |
| 3.3.1                                   | Collection of soil sample and isolation of microbial species                           | 29 |
| 3.3.2                                   | Selection of potential microbial species for the biodegradation of phenol              | 30 |
| 3.3.3                                   | Identification of microbial species  | 31 |
| 3.4                                     | Analytical methods   | 32 |
| <b>Section A: Phenol Biodegradation</b> |  |    |
| 3.5                                     | Biodegradation of phenol in the free cell system                                       | 33 |
| 3.5.1                                   | Process variables optimization   | 33 |
| 3.5.2                                   | Growth kinetic models  | 33 |
| 3.6                                     | Biodegradation of phenol in a packed bed bioreactor                                    | 34 |
| 3.6.1                                   | Packed bed bioreactor set up, immobilization, and operation                            | 34 |
| 3.6.2                                   | External mass transfer analysis in Bioremediation of phenol in a packed bed bioreactor | 37 |
| 3.6.2.1                                 | The external liquid film diffusion process   | 37 |
| 3.6.2.2                                 | Phenol biodegradation rate constant  | 37 |
| 3.6.2.3                                 | Combined mass transport kinetics and phenol degradation                                | 38 |
| 3.6.2.4                                 | A model formulation for phenol biodegradation  | 39 |
| 3.7                                     | Phenol biodegradation in a moving bed biofilm reactor                                  | 40 |
| 3.7.1                                   | Description of modified carrier and reactor set-up                                     | 40 |
| 3.7.2                                   | Process parameters optimization using response surface methodology                     | 42 |

---

---

|   |   |              |
|---|---|--------------|
| 3.7.3   | Substrate utilization rate kinetics   | 42           |
| 3.7.3.1   | First-order kinetic model   | 42           |
| 3.7.3.2   | Second-order kinetic model (Grau model)   | 43           |
| 3.8   | Phytotoxicity analysis  | 44           |
| <b>Section B: 4-chlorophenol Biodegradation</b>   |   |              |
| 3.9   | Effect of biogenic substrate on biodegradation of 4-chlorophenol  | 46           |
| 3.9.1   | Bioreactor set-up, immobilization, and operating procedure  | 46           |
| 3.9.2   | Experimental design using response surface methodology (RSM)  | 46           |
| 3.9.3   | Kinetic study   | 47           |
| 3.9.3.1   | Monod model   | 47           |
| 3.9.3.2   | Modified-Stover Kincannon model   | 48           |
| <b>Section C: Comparative analysis of a packed bed bioreactor and a moving bed bioreactor</b> |   |              |
| 3.10  | Comparative analysis of a packed bed bioreactor and a moving bed bioreactor for 4-chlorophenol Biodegradation | 49           |
| 3.10.1  | Experimental set-up: bioreactor start-up and operation  | 49           |
| <b>Chapter 4. Results and Discussions</b>   |   | <b>52-97</b> |
| <b>Section A: Phenol biodegradation</b>   |   |              |
| 4.1   | Selection of potential microbial species  | 52           |
| 4.2   | Identification of microbial species   | 53           |
| 4.3   | Process variables optimization in free system   | 54           |
| 4.3.1   | Effect of pH  | 54           |
| 4.3.2   | Effect of temperature   | 55           |
| 4.3.3   | Effect of initial phenol concentration  | 56           |

---

---

|   |  |    |
|---|--|----|
| 4.4   | Substrate inhibition models  | 57 |
| 4.5   | Phenol biodegradation in a packed bed bioreactor                                 | 59 |
| 4.5.1   | Morphological characteristics of the biocarrier                                  | 59 |
| 4.5.2   | Performance evaluation of a continuous packed bed bioreactor                     | 60 |
| 4.5.3   | External mass transfer analysis  | 62 |
| 4.6   | Phenol biodegradation in a moving bed biofilm reactor                            | 67 |
| 4.6.1   | Morphological characteristics of the biofilm carrier                             | 68 |
| 4.6.2   | Optimization of pH, HRT, and air flow rate by using RSM technique                | 69 |
| 4.6.2.1   | Process optimization   | 70 |
| 4.6.2.2   | Effect of process variables on phenol and ammonia removal                        | 71 |
| 4.6.2.3   | Development of correlations for the response variables using ANOVA and CCD model | 72 |
| 4.6.2.4   | Verification of the developed model  | 73 |
| 4.6.3   | Kinetic study  | 74 |
| 4.6.3.1   | First-order kinetic model  | 74 |
| 4.6.3.2   | Second-order kinetic model   | 75 |
| 4.7   | Phytotoxicity analysis   | 77 |
| 4.8   | Analysis of metabolites during biodegradation of phenol                          | 78 |
| <b>Section B: 4-chlorophenol biodegradation</b> |  |    |
| 4.9   | Optimization study   | 80 |
| 4.10  | Simultaneous effect of process parameters on 4-CP and COD removal                | 82 |
| 4.10.1  | Effect of 4-CP concentration and peptone concentration                           | 83 |
| 4.10.2  | Effect of HRT and peptone concentration  | 83 |

---

---

|   |  |         |
|---|--|---------|
| 4.10.3  | Effect of 4-CP concentration and HRT                                     | 84      |
| 4.10.4  | Verification of the developed model                                      | 88      |
| 4.11  | Kinetic analysis   | 88      |
| 4.11.1  | Monod model  | 88      |
| 4.11.2  | Modified Stover-Kincannon model  | 89      |
| 4.12  | Phytotoxicity analysis   | 91      |
| <b>Section C: Comparison of efficiency of a packed bed and a moving bed biofilm reactor</b> |  |         |
| 4.13  | Effect of HRT on the performance of MBBR and PBBR                        | 93      |
| 4.14  | Effect of 4-CP concentration and ILR on the performance of MBBR and PBBR | 95      |
| <b>Chapter 5. Conclusions</b>   |  | 99-102  |
| <b>References</b>   |  | 105-122 |
| <b>Appendix</b>   |  | 123-127 |
| <b>List of research publications</b>  |  | 128-130 |

---

# List of figures

| Figure no.        | Figure caption  | Page no. |
|-------------------|---|----------|
| <b>Figure 1</b>   | Chemical structures of phenol and some of its derivative compounds  | 2        |
| <b>Figure 2</b>   | The metabolic pathway for phenol biodegradation in aerobic condition via meta and ortho pathways  | 14       |
| <b>Figure 3.1</b> | Process flow diagram of acclimatization and isolation of microbial species  | 30       |
| <b>Figure 3.2</b> | Schematic diagram of PBBR set up for the removal of phenol  | 36       |
| <b>Figure 3.3</b> | A schematic representation of a MBBR for phenol treatment   | 41       |
| <b>Figure 3.4</b> | Process flow diagram of phytotoxicity analysis in distilled water (control), untreated wastewater, and treated wastewater   | 45       |
| <b>Figure 3.5</b> | Schematic representation of moving bed bioreactor (MBBR) and packed bed bioreactor (PBBR) for 4-CP biodegradation   | 49       |
| <b>Figure 4.1</b> | Schematic representation of removal efficiency of phenol by isolated microbial species (phenol concentration = 100 mg/L, pH = 7.0, temperature = 35 °C, time = 10 days) | 51       |
| <b>Figure 4.2</b> | Phylogenetic tree of isolated bacterial species <i>Bacillus flexus</i> GS1 IIT (BHU) (MK850444.1) for biodegradation of phenol  | 52       |
| <b>Figure 4.3</b> | Effect of pH on the removal of efficiency phenol in free cell (phenol concentration = 150 mg/L, temperature = 30 °C)  | 54       |
| <b>Figure 4.4</b> | Effect of temperature on the removal efficiency of phenol in free cell (phenol concentration = 150 mg/L, pH = 7.0)  | 55       |
| <b>Figure 4.5</b> | Effect of the initial phenol concentration on the removal efficiency of phenol in free cell (pH = 7.0, temperature = 30 °C)   | 56       |
| <b>Figure 4.6</b> | Graph plotted between specific growth rates against phenol  | 57       |



---

|                    |   |    |
|--------------------|---|----|
|                    | concentrations using (a) Monod model, (b) Andrew-Haldane model  |    |
| <b>Figure 4.7</b>  | SEM images of low-density polyethylene (a) before immobilization (blank), (b) after immobilization  | 59 |
| <b>Figure 4.8</b>  | Effect of various flow rates on removal efficiencies of phenol in a continuously operated packed bed bioreactor; $C_0 = 100$ mg/L, pH = $7.0 \pm 0.2$ , temperature = $30 \pm 3$ °C                                 | 61 |
| <b>Figure 4.9</b>  | The straight-line plot between $\frac{1}{k_p}$ against $\frac{1}{G^n}$ for various values of $n$ ( $R^2 > 0.97$ for all values of $n = 0.33, 0.5, 0.7, 0.8, 1.0$ )  | 64 |
| <b>Figure 4.10</b> | The plot of $\ln K_m$ vs. $\ln G$ for evaluation of $N$ and $n$ .   | 65 |
| <b>Figure 4.11</b> | SEM images of PP-PUF (a) before immobilization (b) after immobilization   | 66 |
| <b>Figure 4.12</b> | The effect of simultaneous variation of AFR and pH on the removal of (a, b) phenol; (c, d) COD; (e, f) ammonia  | 70 |
| <b>Figure 4.13</b> | First-order kinetic model plot for the removal of phenol, ammonia, and COD  | 74 |
| <b>Figure 4.14</b> | Second-order kinetic model plot for the removal of phenol, ammonia, and COD   | 75 |
| <b>Figure 4.15</b> | Images of <i>Vigna radiata</i> seeds germinated in (a) distilled water, (b) untreated wastewater, (c) treated wastewater  | 77 |
| <b>Figure 4.16</b> | GC-MS analysis of (a) phenol (control); (b) treated wastewater  | 78 |
| <b>Figure 4.17</b> | GC-MS spectra of control (a) phenol and intermediate metabolites (b) catechol and (b) 2-hydroxymuconic semialdehyde   | 79 |
| <b>Figure 4.18</b> | The response surface methodology plots for the biodegradation of 4-CP: (a, b) effect of peptone and 4-CP concentration; (c, d) effect of HRT and peptone concentration; (e, f) effect of HRT and 4-CP concentration | 84 |

---

---

|                    |  |    |
|--------------------|--|----|
| <b>Figure 4.19</b> | The response surface methodology plots for the biodegradation of COD: (a, b) effect of peptone and 4-CP concentration; (c, d) effect of HRT and peptone concentration; (e, f) effect of HRT and 4-CP concentration | 85 |
| <b>Figure 4.20</b> | Monod model plot for the removal of (a) 4-CP, (b) COD  | 88 |
| <b>Figure 4.21</b> | Modified Stover-Kincannon model plot for the removal of (a) 4-CP, (b) COD  | 89 |
| <b>Figure 4.22</b> | Images of <i>Vigna radiata</i> seeds germinated in (a) distilled water, (b) untreated wastewater, (c) treated wastewater (after 7.0 days)  | 91 |
| <b>Figure 4.23</b> | Effect of hydraulic retention time on (a) 4-CP, and (b) COD removal efficiency in MBBR and PBBR  | 93 |
| <b>Figure 4.24</b> | Effect of hydraulic retention time on (a) attached biomass, and (b) mixed liquor suspended solid in MBBR and PBBR  | 94 |
| <b>Figure 4.25</b> | Effect of inlet loading rate and initial 4-CP concentration on (a) 4-CP, and (b) COD removal efficiency in MBBR and PBBR   | 95 |
| <b>Figure 4.26</b> | Effect of inlet loading rate on (a) attached biomass and (b) mixed liquor suspended solids in MBBR and PBBR  | 96 |

---

# List of tables

| Table no.        | Table caption   | Page no. |
|------------------|---|----------|
| <b>Table 1</b>   | Summary of advantages and disadvantages of various methods used for wastewater treatment  | 7        |
| <b>Table 2.1</b> | A summary of microbial cells used for biodegradation of phenol and derivatives  | 15       |
| <b>Table 2.2</b> | Various bioreactors used for biodegradation of phenol and its derivatives   | 22       |
| <b>Table 3.1</b> | Composition of MSM used for the preparation of wastewater   | 29       |
| <b>Table 3.2</b> | Dimensional specifications, conditions, and outcomes of the PBBR  | 36       |
| <b>Table 3.3</b> | The design details of MBBR and PBBR and characteristics of the biocarrier   | 50       |
| <b>Table 4.1</b> | Monod and Andrew-Haldane kinetic parameters for biodegradation of phenol  | 59       |
| <b>Table 4.2</b> | Effect of the flow rate and inlet loading rate on removal efficiency and elimination capacity of packed bed bioreactor (PBBR)                               | 61       |
| <b>Table 4.3</b> | Experimentally calculated values of $k_p$ (obtained from <a href="#">Eq (10)</a> ) and measured values of $G$ , $I/G^n$ , $I/k_p$ at different flow rates   | 64       |
| <b>Table 4.4</b> | Slope and intercept obtained from the graph plotted between $I/k_p$ vs. $I/G^n$ at corresponding values of $n$  | 64       |
| <b>Table 4.5</b> | Evaluated values of $N$ , external mass transfer area ( $a_m$ ), intrinsic first-order reaction rate constant ( $k_s$ ) for different values of $n$ and $K$ | 64       |
| <b>Table 4.6</b> | Calculated values of mass transfer coefficient ( $k_m$ ) at different mass fluxes ( $G$ ) for $n= 0.7$ and $K=1.625$  | 65       |

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|                   |  |    |
|-------------------|--|----|
| <b>Table 4.7</b>  | Comparison data of $k_p$ values obtained from Eq (10) to those ones calculated from Eq. (18) for different values of $n$           | 66 |
| <b>Table 4.8</b>  | Experimentally obtained responses at various conditions used in RSM optimization   | 70 |
| <b>Table 4.9</b>  | Analysis of fit summary statistics obtained from RSM   | 70 |
| <b>Table 4.10</b> | ANOVA analysis for the quadratic model fitted to various responses   | 73 |
| <b>Table 4.11</b> | Summary of kinetic parameters obtained by first-order and second-order model for removal of phenol, COD, and ammonia, respectively | 77 |
| <b>Table 4.12</b> | A summary of toxicity analysis of treated and untreated wastewater by <i>Vigna radiata</i> seed germination                        | 78 |
| <b>Table 4.13</b> | Experimentally obtained responses at various conditions used in RSM optimization   | 82 |
| <b>Table 4.14</b> | Analysis of fit summary statistics obtained from RSM   | 87 |
| <b>Table 4.15</b> | ANOVA analysis for the quadratic model fitted to various responses   | 87 |
| <b>Table 4.16</b> | Summary of kinetic parameters obtained by Monod and modified Stover-Kincannon model for removal of 4-CP and COD, respectively      | 91 |
| <b>Table 4.17</b> | A summary of toxicity analysis of treated and untreated wastewater by <i>Vigna radiata</i> seed germination                        | 92 |
| <b>Table 4.18</b> | The summary of experimental results obtained from continuous operation of a moving bed bioreactor                                  | 98 |
| <b>Table 4.19</b> | The summary of experimental results obtained from continuous operation of a packed bed bioreactor                                  | 98 |

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# Abbreviations

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| Abbreviation | Nomenclature                                      |
|--------------|---|
| 4-CP         | 4-chlorophenol                                    |
| 2,4-DCP      | 2,4-Dichlorophenol                                |
| P-NP         | Para-Nitrophenol                                  |
| DO           | Dissolved oxygen (mg/L)                           |
| PBBR         | Packed bed bioreactor                             |
| LDPE         | Low-density polyethylene                          |
| PUF          | Poly urethane foam                                |
| PP           | polypropylene                                     |
| HRT          | Hydraulic retention time (h)                      |
| RE           | Removal efficiency (%)                            |
| EC           | Elimination capacity (mg/L.d)                     |
| ILR          | Inlet loading rate (mg/L.d)                       |
| MSM          | Minimal salt medium                               |
| MBBR         | Moving bed biofilm reactor                        |
| RSM          | Response surface methodology                      |
| COD          | Chemical oxygen demand (mg/L)                     |
| CCD          | Central composite design                          |
| $\mu_{max}$  | Maximum specific growth rate (day <sup>-1</sup> ) |
| $K_s$        | Half-saturation constant (mg/L)                   |
| $K_i$        | Substrate inhibition constant                     |

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|            |  |
|------------|--|
| $S_0, F_0$ | Initial substrate concentration (mg/L)       |
| $S, F$     | Final substrate concentration (mg/L)         |
| $U_{max}$  | Maximum substrate utilization rate (mg/L. d) |
| $X$        | Biomass concentration (mg/L)                 |
| $V$        | Volume of the bioreactor (L)                 |
| $Q$        | Feed flow rate (mL/h)                        |

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# Preface

Industrialization has improved the living style and economic prospects of the people as well as the country. In the meantime, the toxic pollutants (mainly phenol, phenolic derivatives, dyes, polycyclic aromatic hydrocarbons, etc.) are discharged to the ecosystem by various industries like petroleum, pharmaceutical, paints, and pesticides, and cause environmental issues. The carcinogenic, mutagenic, and teratogenic properties of the pollutants make researchers to explore cost-effective and eco-friendly technology for the degradation of such pollutants. In this direction, the biodegradation process is preferred as an effective tool for the mineralization of xenobiotic compounds.

The adopted microorganisms which have a history of exposure to the contaminated site exhibit higher biodegradation rates than other microorganisms. Hence, the acclimatization and isolation of the potent microbial species can enhance the biodegradation rate. The real-time applications of various microorganisms and packing support have been widely studied for wastewater treatment. However, the continuous performance evaluation of attached-growth bioreactors, such as packed bed bioreactor (PBBR) and moving bed bioreactor (MBBR), are relatively less researched for such applications. The objective of this study is to evaluate the efficacy of the potential bacterial species isolated from a petroleum contaminated site for the biodegradation of phenol and its derivatives in the PBBR and MBBR. In addition, this study employed the low-density polyethylene and polyurethane foam, a packaging waste, in bioreactors for the purpose of bacterial immobilization. A comparative analysis has also been carried out to investigate the performance of PBBR and MBBR operated at identical conditions.

The present thesis is categorized into **5 chapters**. **Chapter 1** embeds the introduction (sources and toxic effect) of phenol and its derivatives, treatment methods, and various

factors affecting the biodegradation process. **Chapter 2** contains a detailed analysis of the literature review, research gaps, and the objective of the thesis work. **Chapter 3** includes the materials and methods of the experimental work. The results and discussions (phenol biodegradation, 4-chlorophenol biodegradation, and comparative study between PBBR and MBBR) are briefly explained in **Chapter 4**. The conclusions of the thesis work and the scope for future work have been mentioned in **Chapter 5**.